ULYSSES OBSERVA'I'IONS OF SOLAR WIND PLASMA PARAMETERS IN THE ECLIPTIC FROM 1.4 10 5.4 AU ANI) OUT OF THE ECLIPTIC

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ABSTRACT We report observations of radial and latitudinal gradients of Ulysses plasma parameters. The solar wind velocity increased rapidly with latitude from 0° to 35°, then remained approximately constant at higher latitudes. Solar wind density decreased rapidly from 0° to 35° of latitude, and also was approximately constant beyond that latitude. The mass flux similarly decreased away from the equator (but less than the density), whereas the momentum flux was relatively constant. The radial gradient of the entropy at high latitude indicated a value for the polytrope index of about 1.72 (close to adiabatic); the in-ecliptic estimates of radial gradients for temperature and entropy may be biased by temporal variation. A striking increase in the alpha particle-proton velocity difference with latitude is found.

1. Observations

As Ulysses climbed in latitude it encountered a recurrent high-speed stream arising from an equatorward extension of the South Polar Coronal Hole (Bame et al., 1993); followed by steady immersion in the high speed stream (Phillips et al. 1994) We display in Fig. 1 the solar wind proton velocity, for data obtained since June 30, 1992, as a
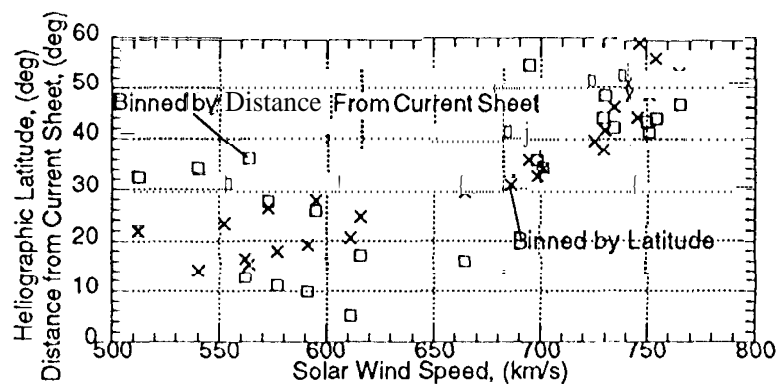
function of heliospheric latitude, and as a function of angular distance from the current sheet in degrees, both averaged over solar rotations.. The angular distance from the current sheet was estimated by determining the location of the current sheet from the

Stanford source surface data, and tracing back to the Sun using the measured velocity. The data arc similar at the highest latitudes, but the current sheet distance binned averages do not show the low velocities at low latitudes that are apparent in the heliolatitude averages. Significant errors can occur from the constant velocity assumption, and, the source surface model exagerrates the distance of the current sheet from the equatorial plane Schulz, 1994). Heliographic coordinate are used in the rest of this paper,
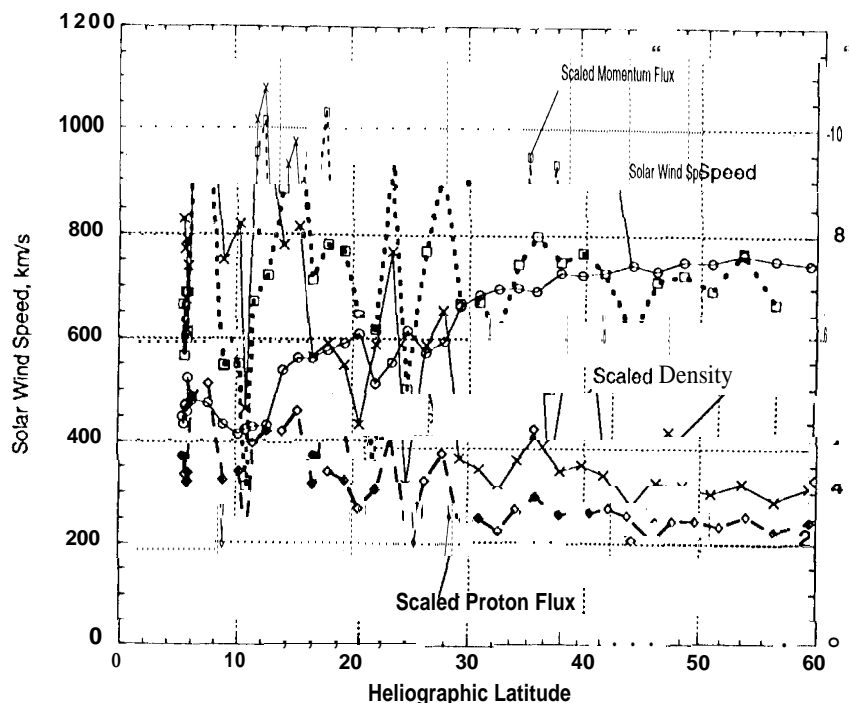

Fig. 2 shows data from Sept. 12 of 1991, at which time Ulysses was about 4.15 AU from the Sun, to the end of currently available data, March 26, 1994, when the distance was 3.4 AU. Shown are proton bulk speed, VP, (km/s), scaled (to 1 AU) density, $r^2 n_p$, (/cm^3), scaled number flux, $r^2 n_p V_p$, (km/sec) /cm^3 10^{-3}) , and scaled momentum flux (including alpha particles, magnetic terms, and electron pressure, dynes cm^{-2} 2x10^8), all averaged over solar rotations. The velocity axis is on the left, on the right are density, mass flux divided by 1000 and momentum flux divided by 50000. The in-ecliptic velocity of the solar wind is -450 km/see, increasing rapidly over the range from 5° to 35° to -700 km/sec. From 35° to 55° the velocity increases from -700 km/sec to -750 km/see, and by 550 the velocity seems to be no longer increasing in these rotation-binned data (but McComas ct al. 1994, find a modest gradient examining these data with higher latitudinal resolution). The scaled density drops precipitously from an in-ecliptic value of about 8.6 /cc to a value of 3.7 /cc, The proton flux decreases with latitude by about 35% from 0° to 40°, which is less than the decrease in density. Similarly, the decrease in radial momentum flux is even less, -10%.

The genera] tendency of density and velocity to be anticorrelated is typical of what is observed at low latitudes in the solar wind.
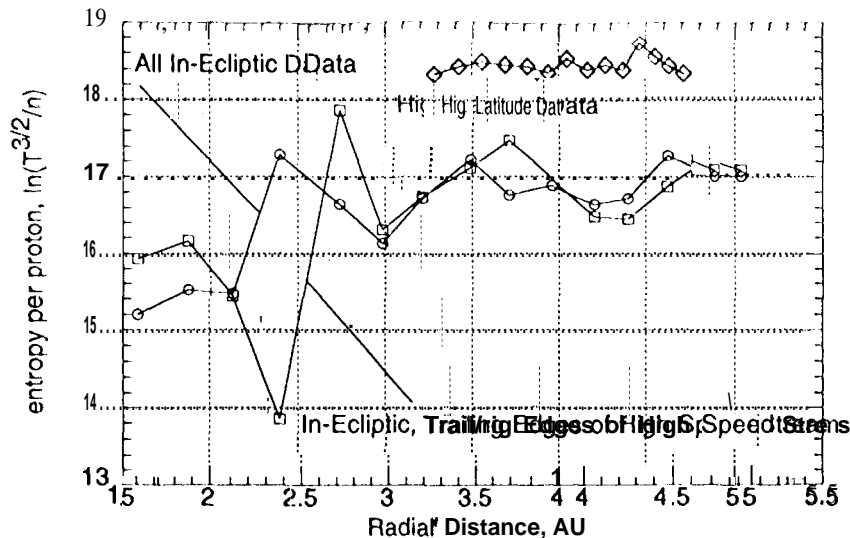
The solar wind proton distribution is much hotter at high latitudes than at low latitudes. The entropy per proton, $\ln(T^{3/2}/n)$, averaged over each solar rotation as seen from Ulysses, is shown in Fig. 3 which compares high latitude observations and two selections of in-ecliptic data. The in-ecliptic data period for Fig. 3 is from Dec. 18, 1990, when nutation ceased, to January 20 , 1992 (ending before Jupiter encounter, a range of 1,4 to 5.2 AU). The high latitude observations were obtained at latitudes of from 30° to 57° while the spacecraft traveled from 4.76 to 3.4 AU. The in-ecliptic data shown are for two cases, the full data set and a data set restricted to the trailing edges of high speed streams, Since coronal mass ejections have different thermal properties, they were excluded. The entropy at high latitudes is very much greater than in the ecliptic; there are large latitudinal entropy and temperature gradients. At high latitudes the entropy does not appear to be increasing with distance from the Sun as is seen at lower latitudes; a logarithmic fit to the data provides an equivalent polytrope index of 1,72 (close to adiabatic expansion). If all the in-ecliptic observations are used, there is apparently a large increase of entropy with distance from the Sun, correspondingly, the temperature (not shown) decreases with distance from the Sun much more slowly than predicted by adiabatic expansion. Heating by shocks or other effects at corotating interaction regions should not affect trailing edges of high speed streams, yet, this data has an entropy increase with distance similar to that of the full data set, From a logarithmic fit in r, and assuming a r^{-2} dependence of density upon distance from the Sun, the resulting polytrope indices, y, are: 1.20 (all in-ecliptic data), 1.16 (trailing edge in-ecliptic data). However, examining the temperature variations indicates that temporal effects may be as important as spatial effects.
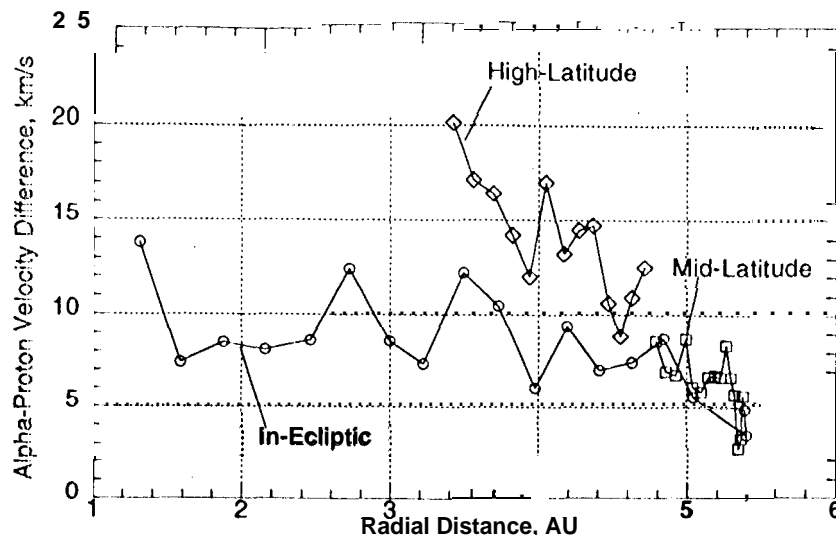
In the solar wind at 1 AU, relative streaming between alpha-particles and protons is typically observed in high speed streams. However, Nuegebauer et al. (1994) found that in the Ulysses plasma observations such relative streaming occurs less frequently beyond 1 AU. Further, when relative streaming does occur it is not associated with high speed streams, but rather occurs in the vicinity of solar wind shocks. Fig. 4 shows the alpha-proton velocity difference for three different regimes, in-ecliptic, 1Oo to 300 (mid-latitude), and >30° (high latitude). As **Ulysses enters the high latitude** region, there is a large increase in the relative streaming with the velocity difference being relatively constant and about half the Alfvén speed. Such large relative streaming was not observed in the ecliptic plane, and might be **due to reduced Coulomb collisions.**

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